

## **Long-Duration Space Flight Provokes Pathologic Q-Tc Interval Prolongation**

D'Aunno      Q-Tc Prolongation with Space Flight

Dominick S. D'Aunno, MD, Anne H. Dougherty, MD, Heidi F. DeBlock, MD, and  
Janice V. Meck, PhD,

Dominick S. D'Aunno, MD, National Space Biomedical Research Institute, Baylor  
College of Medicine, Houston, TX

Anne H. Dougherty, MD, University of Texas Medical School at Houston, Houston, TX

Heidi F. DeBlock, MD, Albany Medical College, Albany, NY

Janice V. Meck, PhD, NASA-Johnson Space Center, Space and Life Sciences  
Directorate, Cardiovascular Laboratory, Houston, TX

### **Correspondence:**

Dominick S. D'Aunno, MD NASA-Johnson Space Center, Mail Code SK, bldg 261,  
Cardiovascular Laboratory, Houston, TX 77058

281-483-5542      (Fax) 281-483-4181

[ddaunno@ems.jsc.nasa.gov](mailto:ddaunno@ems.jsc.nasa.gov)

Research Support: 96-OLMSA-01-051 NASA

**Journal Subject Heads:** [5] Arrhythmias, clinical electrophysiology, drugs

Word Count: 4,170

## **Abstract**

**Background** – Space flight has a profound influence on the cardiovascular and autonomic nervous systems. Alterations in baroreflex function, plasma catecholamine concentrations, and arterial pressure regulation have been observed. Changes in autonomic regulation of cardiac function may lead to serious rhythm disturbances. In fact, ventricular tachycardia has been reported during long-duration space flight. The study aim was to determine the effects of space flight on cardiac conduction.

**Methods and Results** –Electrocardiograms (ECGs) and serum electrolytes were obtained before and after short-duration (SD) (4-16 days) and long-duration (LD) (4-6 months) missions. Holter recordings were obtained from 3 different subjects before, during and after a 4-month mission. P-R, R-R, and Q-T intervals were measured manually in a random, blinded fashion and Bazett's formula used to correct the Q-T interval (Q-Tc). Space flight had no clinically significant effect on electrolyte concentrations. P-R and R-R intervals were decreased after SD flight ( $p<0.05$ ) and recovered 3 days after landing. In the same subjects, P-R and Q-Tc intervals were prolonged after LD flight ( $p<0.01$ ). Clinically significant Q-Tc prolongation ( $>0.44$  sec) occurred during the first month of flight and persisted until 3 days after landing ( $p<0.01$ ).

**Conclusions** – Space flight alters cardiac conduction with more ominous changes seen with LD missions. Alterations in autonomic tone may explain ECG changes associated with space flight. Primary cardiac changes may also contribute to the conduction changes with LD flight. Q-Tc prolongation may predispose astronauts to ventricular arrhythmias during and after long-duration space flight.

### **Condensed Abstract**

Space flight-induced changes in autonomic regulation of cardiac function may lead to serious rhythm disturbances. The study aim was to determine the effects of space flight on cardiac conduction. P-R, R-R, and Q-T intervals were measured from ECGs before and after short- and long-duration flight. The same intervals were measured from Holter recordings before, during, and after a 4-month mission. P-R and R-R intervals were significantly decreased after short-duration flight. P-R, R-R, and Q-Tc intervals were significantly prolonged after long-duration flight (Q-Tc prolongation  $>0.44\text{sec}$ ). Long-duration space flight may predispose astronauts to malignant ventricular arrhythmias.

**Keywords:** Q-T Prolongation, Space Flight, Electrophysiology, P-R Interval

The cardiovascular system undergoes profound changes when exposed to the microgravity environment of space flight. Functional aspects of the autonomic nervous system, such as baroreflex responses and blood pressure variability, are significantly affected.<sup>1,2</sup> Alterations in cardiovascular autonomic regulation could adversely influence cardiac conduction and precipitate cardiac rhythm disturbances. In fact, ventricular and supraventricular dysrhythmias have been observed during space flight.<sup>3-8</sup> Serious cardiac arrhythmias could have a catastrophic impact on crew health and mission objectives. However, space flight-induced changes in cardiac conduction have not been systematically examined.

The majority of information available regarding cardiovascular changes associated with space flight has been restricted to short-duration Space Shuttle flights (5-16 days). As astronauts spend greater amounts of time in space (4-6 months), flight duration-dependent differences in cardiovascular responses are emerging. For example, the incidence of presyncopal symptoms at landing increases significantly after long-duration flight.<sup>9</sup> While previous work in this laboratory has shown that short-duration space flight has no effect on the incidence of cardiac dysrhythmias, an episode of ventricular tachycardia was observed during a long-duration mission onboard the Russian space station Mir.<sup>3,10</sup> This was the first time such a dramatic change in cardiac rhythm had been published. Alterations in autonomic function might contribute to the increase in orthostatic intolerance and cardiac rhythm disturbances. Therefore, it is important that autonomic changes and cardiac conduction be adequately examined. As astronauts are required to spend greater amounts of time in space, it is imperative to determine if a

prolonged exposure to weightlessness will have a deleterious effect on cardiac conduction and arrhythmia potential.

We analyzed ECGs or recordings from Holter monitors taken from astronauts who experienced short- and long-duration space flight. Our findings reveal striking differences between short- and long-duration space flight. The data also demonstrate alarming in-flight changes in cardiac conduction during long-duration space flight that persist for many days after landing.

## **Methods**

Informed consent was obtained in accordance with the guidelines of the Committee for the Protection of Human Subjects at the Johnson Space Center. A retrospective analysis of electrocardiograms from seven astronauts, who experienced both short-duration space flight onboard the Space Shuttle and long-duration space flight onboard the Russian Space Station Mir or International Space Station, were utilized to measure P-R, R-R, and Q-T intervals. Three-lead ECGs were recorded on digital tapes preflight (10 days before space flight), on landing day, and 3 days after re-entry for both short- and long-duration missions. One minute of resting data were analyzed from lead II and the results averaged for each test day.

24-hour Holter monitor recordings, from 3 different crewmembers, were taken preflight (60 days before launch), at 3 separate times during the mission (4 month flight), 2 times after transfer to the Space Shuttle before re-entry, on landing day (one subject's Holter

was taken 2 days after landing) and at 11 or 39 days after landing. P-R, R-R, and Q-T intervals from lead II were measured for 10 cardiac cycles one hour after the Holter monitors were donned at the start of the duty day and the results for each interval were averaged for each test day. Activity logs are not available.

The P-R, R-R and Q-T intervals were measured manually, in a random order, by 2 examiners that were blinded to the flight duration or testing day. The results for each interval were averaged. The beginning of the P wave and the beginning of the QRS complex defined the P-R interval. The beginning of the Q (or R) wave and the end of the T wave at the isoelectric point defined the Q-T interval. The Q-T interval was then corrected for heart rate using Bazget's formula  $Q-T_c = Q-T / (R-R)^{0.5}$ .

ECG data from one long-duration astronaut were not collected 3 days after landing. Five of the seven astronauts from long-duration space flights had complete ECG data sets available from previous short-duration space flights for comparison.

Serum concentrations of potassium, calcium, and magnesium were measured preflight, on landing day, and 3 days after landing.

Data were checked for normalcy and are expressed as the Mean  $\pm$  SE. Student's t-test or paired t-tests were used to determine if space flight duration had an effect on P-R, R-R, or Q-T<sub>c</sub> intervals. Paired t-tests were used to determine if space flight duration had an effect on serum concentrations of potassium, calcium, or magnesium. Significance was set at  $P < 0.05$ .

## Results

Table 1 shows the concentrations for potassium, calcium, and magnesium. Although there is a statistically significant decrease in the concentration of potassium on landing day after long-duration space flight ( $P=0.002$ ), clinically, there were insufficient changes in electrolyte levels to affect cardiac conduction.

Figure 1 represents one minute of supine Q-Tc data for a single astronaut. Preflight data is shown on the left. Individual Q-Tc intervals on landing day after short- and long-duration space flights are shown in the middle and right, respectively. After short-duration flight, none of the Q-Tc intervals were prolonged. After long-duration flight, there is a dramatic increase in the number of prolonged Q-Tc intervals. Twenty seven percent of the Q-Tc intervals are 0.44 seconds or greater after long-duration flight.

## Comparison Between Short- and Long-Duration Space Flight

Preflight values for, P-R, R-R, and Q-Tc intervals were similar for both short- and long-duration space flights. On landing day, the P-R and Q-Tc intervals were significantly increased after long-duration space flight (Figure 2) ( $P=0.014$ ,  $P=0.012$ ). The decrease in R-R interval observed on landing day after short-duration space flight is not present after long-duration space flight ( $P=0.034$ ) (Figure 3). Three days after landing, the R-R interval was significantly shorter after long-duration space flight ( $P<0.001$ ).

## **Holter Monitoring During Long-Duration Space Flight**

Figure 4 shows changes in P-R intervals with respect to space flight duration for 3 subjects. P-R intervals were normal preflight. The P-R interval increased during the mission in all subjects. After transfer to the Space Shuttle, all 3 subjects showed a decrease in the P-R interval. By Shuttle Day 3, the P-R interval lengthened. On landing day, all of the subjects had P-R intervals greater than preflight measurements. The P-R intervals were decreased during postflight testing.

Figure 5 shows changes in Q-Tc intervals with respect to space flight duration for 3 subjects. Q-Tc intervals were normal preflight. By the first month of flight, there is a dramatic increase for each subject. Values greater than 0.44 seconds persisted during the 4-month mission and were present on landing day. After transfer to the Space Shuttle, there is a decrease in the Q-Tc on Shuttle Day 1 that remained at this duration for 2 subjects, while one subject had a prolongation of the Q-Tc on Shuttle Day 3. Q-Tc intervals remained abnormal for at least 11 days.

Figure 6 shows changes in R-R intervals with respect to space flight duration for 3 subjects. There is an increase in R-R intervals for all subjects by the first month in space that remained elevated for the duration of the mission. The R-R intervals did not change after the subjects had transferred to the Space Shuttle and all subjects showed a shortening of the R-R interval on landing day. On Day 11 after landing, 2 subjects had R-R intervals that were shorter than preflight values. On Day 39 after landing, one subject had an increase R-R interval compared to preflight.

## Discussion

The major finding of this study is that space flight affects cardiac repolarization processes. The specific findings are: 1) P-R, R-R and Q-Tc interval durations are significantly affected by space flight; 2) long-duration flight results in clinically abnormal Q-Tc intervals which persists after landing; 3) inflight transfer from one spacecraft to another results in dramatic changes in cardiac conduction; 4) the severity of in-flight Q-Tc interval prolongation may be underestimated from landing day data alone and 5) R-R intervals are reduced after short- but not after long-duration space flight.

The P-R, R-R, and Q-T intervals of the electrocardiogram are modulated by sympathetic and parasympathetic activity. A relative increase in sympathetic to parasympathetic activity will shorten,<sup>11-13</sup> and a relative increase in parasympathetic activity will lengthen all three.<sup>12-18</sup> Examination of these intervals before, during and after space flight, allows one to infer shifts in sympathovagal balance. Other conditions such as intrinsic conduction abnormalities, changes in electrolyte levels, and serum catecholamine concentration may also influence cardiac conduction.

In the current subject population, cardiovascular disease and intrinsic conduction abnormalities can be ruled out. All astronauts are thoroughly screened for these conditions. Changes in concentrations of potassium, calcium, and magnesium were not clinically significant (Table 1) and probably did not contribute to P-R, R-R, or Q-Tc interval changes.

## Short-Duration Space Flight

A relative increase in sympathetic to parasympathetic activity, or a greater catecholamine concentration could explain the shorter P-R and R-R intervals observed on landing day. Previous work in this laboratory supports this hypothesis. After short-duration flight, vagally-mediated responses to carotid baroreceptor stimulation are reduced,<sup>2</sup> cardioacceleration in response to standing and during Valsalva maneuvers are exaggerated<sup>2,19</sup> and power spectral analysis of R-R intervals reveal an increase in the ratio of low to high frequency power.<sup>2</sup> All of these indicate sympathetic activation. To corroborate that, resting catecholamine levels are significantly increased on landing day.<sup>20,21</sup> Although sympathetic nerve activity was not directly measured in these earlier studies, a more recent study demonstrated increased sympathetic nerve activity on landing day after short-duration space flight.<sup>22</sup>

Within the milieu of heightened sympathetic activity on landing day, and in light of the decreases in P-R and R-R intervals, one would also expect the Q-Tc interval to be similarly decreased. The fact that Q-Tc interval was not might reflect a  $\beta$ -statistical error due to the high degree of variability and small sample size (n=5). Future studies on a larger sample size, with preflight, inflight, and postflight ECG data should better define the influence of short-duration space flight on Q-Tc interval.

## Long-Duration Space Flight

Both during and after long-duration space flight, the P-R, R-R and Q-Tc intervals were prolonged. The Q-Tc prolongation was clinically significant from the first month of flight through the eleventh day after landing, with only a transient reduction in length when the astronauts transferred from Mir to Shuttle. This is an important finding because so little is known about the effects of long-duration flight on cardiac conduction. P-R interval prolongation has been observed during long-duration missions onboard Skylab and the authors suggested increased vagal activity as a contributing factor.<sup>6</sup> Q-Tc interval prolongation was also noted in the later phase of Skylab missions.<sup>23</sup>

In the present study the 3 crewmembers, who underwent Holter monitoring during long-duration space flight, showed P-R and Q-Tc prolongations that were even greater than those observed on landing day for the seven astronauts studied only before and after flight. This indicates that landing day measurements may underestimate the magnitude of the effect and that the changes in conduction are not a phenomenon of landing itself.

We were fortunate to have landing day supine and standing norepinephrine (NE) concentrations in one subject after both short- and long-duration space flight.<sup>9</sup> The data show that after long-duration flight, the increase in NE with standing was 100-fold smaller than it had been after short-duration flight. Although one subject is not definitive, this absence of NE response to orthostatic stress supports the theory of diminished sympathetic activity after long-duration space flight. Further evidence of

diminished sympathetic activity is that the significant reductions in R-R interval seen after short-duration flight are not present after long-duration flight.

It is reasonable to conclude that enhanced sympathetic activity after short-duration space flight causes a shift in sympathovagal balance that is responsible for the observed cardiac conduction changes. This phenomenon does not appear to be clinically relevant.

However, during a more prolonged exposure to space flight, there seems to be a decrease in sympathetic activity that causes an opposite shift in sympathovagal balance that results in greater P-R, R-R, and Q-Tc intervals. The most alarming change in the ECG with respect to long-duration space flight is observed in the Q-Tc interval.

It is generally accepted that a rate corrected Q-T interval of more than 0.44 seconds is abnormal.<sup>13,24</sup> Q-Tc interval prolongation has been associated with an increased susceptibility to serious ventricular arrhythmias and cardiovascular mortality.<sup>11,12,24</sup> Six of the ten subjects we studied had individual Q-Tc intervals above 0.44 seconds on landing day. Regarding the in-flight data, all of the crewmembers had Q-Tc intervals above 0.44 seconds during the entire mission. In one subject the Q-Tc reached 0.52 seconds. After short-duration flights, there were no Q-Tc intervals above 0.44 seconds. Thus, there appears to be a differential effect on ventricular repolarization, due to space flight duration.

A recent study described the role of beta-adrenergic receptor activation in mediating load-dependent shortening of ventricular action potential and refractoriness. In that study, an increase in ventricular load increased catecholamine secretion and stimulated the beta-

adrenergic receptor which increased cAMP. cAMP then augmented activation of the delayed rectifier potassium current,  $I_K$ , which accelerated repolarization and reduced action potential duration and ventricular refractoriness.<sup>25</sup> In-flight studies performed on long-duration Skylab crewmembers suggest a decrease in preload.<sup>26</sup> In addition, we have described a significant decrease in catecholamine concentration in response to orthostatic stress after long-duration flight.<sup>9</sup> Theoretically, reduced preload and sympathetic activity could contribute to reduced activation of  $I_K$ , and prolongation of the Q-Tc interval. It has been shown that mutations in the genes encoding  $I_K$  are responsible for long-QT syndromes.<sup>27</sup>

At the end of their stay on Mir, the subjects transferred to the Space Shuttle and stayed for six days prior to re-entry. This resulted in a transient reduction in P-R and Q-Tc, but not R-R intervals. In contrast, the stress of landing itself caused decreases in the R-R interval, while P-R and Q-Tc intervals remained elevated. These differential effects may indicate that autonomic influence on the sinus node and on intra-cardiac conduction may be altered differentially. In addition there may be primary cardiac changes, possibly in beta-adrenergic receptor activity or potassium ion function, that also contribute to the conduction abnormalities we report.

The main operational concern from these findings is the possibility that serious cardiac arrhythmias, such as torsades de pointes, may occur during or immediately after a long-duration space flight. Although ventricular dysrhythmias have been reported during long-duration space flight,<sup>3,4</sup> there has been no systematic evaluation of their mechanisms or frequency. It is entirely possible that the Q-Tc interval prolongation is a

contributing factor. Our data also suggests that the potential for significant cardiac arrhythmias extends beyond landing day as we see the Q-Tc is prolonged on Day 3 and Day 11 after landing. These data are also relevant to the in-flight pharmacy provided on long-duration flights. Any medication or any combination of medications that are known to increase Q-Tc intervals should be used with extreme caution.

### **Study Limitations**

Four of the crewmembers took medications prior to landing that may have influenced our results. Two crewmembers took 30mg of temazepam the night before landing. Two other crewmembers received 25mg or 50mg of promethazine prior to landing. However, there is no evidence in the literature that these drugs affect cardiac conduction. Thus, we do not believe these medications had any influence on our data.

### **Conclusions**

Space flight significantly affects P-R, R-R, and Q-Tc intervals. Shifts in sympathovagal balance and possible primary changes in the heart may be responsible for the observed effects. P-R and R-R intervals are significantly decreased by short-duration flight. P-R and Q-Tc intervals are significantly prolonged during and after long-duration flight. The prolongation of the Q-Tc interval to a clinically significant value of greater than 0.44 seconds is foreboding. Future studies on autonomic function and cardiac conduction are essential to prevent the development of potentially lethal cardiac arrhythmias in astronauts during and immediately after extended stays in space.

### **Acknowledgments**

I would like to thank Dr. Mary Wear, Epidemiology Section Supervisor of the Longitudinal Study of Astronaut Health, for providing the data on electrolyte concentrations.

## Reference List

- 1 Fritsch JM, Charles JB, Bennett BS, et al. Short-duration spaceflight impairs human carotid baroreceptor- cardiac reflex responses. *J Appl Physiol.* 1992; 73(2):664-671.
- 2 Fritsch-Yelle JM, Charles JB, Jones MM, et al. Spaceflight alters autonomic regulation of arterial pressure in humans. *J Appl Physiol.* 1994; 77(4):1776-1783.
- 3 Fritsch-Yelle JM, Leuenberger UA, D'Aunno DS, et al. An episode of ventricular tachycardia during long-duration spaceflight. *Am J Cardiol.* 1998; 81:1391-1392.
- 4 Pestov ID, Gerathewohl SJ. Weightlessness. In: Calvin M, Gazenko OK, editors. *Foundations of Space Biology and Medicine.* NASA SP-374, 1995: 305-354.
- 5 Bungo MW, Johnson PC, Jr. Cardiovascular examinations and observations of deconditioning during the space shuttle orbital flight test program. *Aviat Space Environ Med.* 1983; 54:1001-1004.
- 6 Smith RF, Stanton K, Stoop D, et al. Vectorcardiographic changes during extended space flight (MO93): Observations at rest and during exercise. In: Johnston RS, Dietlein LF, editors. *Biomedical results from Skylab.* Washington, D.C.: National Aeronautics and Space Administration, 1977: 339-350.
- 7 Hoffler GW, Wolthuis RA, Johnson RL. Apollo space crew cardiovascular evaluations. *Aerosp Med.* 1974; 45:807-820.
- 8 Grigoriev AI, Egorov AD. Long-Term Flight. In: Nicgossian A, Mohler SR, Gazenko OG, Grigoriev AI, editors. *Space Biology and Medicine: Joint U.S./Russian Publication in Five Volumes.* Reston, VA: American Institute of Aeronautics and Astronautics, 1996: 506-507.
- 9 Meck JV, Reyes CJ, Perez SA, et al. Marked exacerbation of orthostatic intolerance after long vs. short-duration spaceflight in veteran astronauts. *Psychosomatic Medicine.* 2001; 63(6):865-873.
- 10 Rossum AC, Wood ML, Bishop SL, et al. Evaluation of cardiac rhythm disturbances during extravehicular activity. *Am J Cardiol.* 1997; 79:1153-1155.
- 11 Murakawa Y, Yamashita T, Ajiki K, et.al. Is the QT interval an indicator of autonomic state? *Jpn Heart J.* 2000; 41(6):713-721.
- 12 Browne KF, Prystowsky E, Heger JJ, et al. Modulation of the Q-T interval by the autonomic nervous system. *Pacing Clin Electrophysiol.* 1983; 6(5 Pt 2):1050-1056.
- 13 Goldberger AL, Goldberger E. Basic ECG Waves. *Clinical Electrophysiology A simplified Approach.* St. Louis: Mosby Year Book, 1990: 7-21.
- 14 Furukawa Y, Narita M, Takei M, et al. Differential intracardiac sympathetic and parasympathetic innervation to the SA and AV nodes in anesthetized dog hearts. *Jpn J Pharmacol.* 1991; 55(3):381-390.

- 15 Cappato R, Alboni P, Pedroni P, et al. Sympathetic and vagal influences on rate-dependent changes of QT interval in healthy subjects. *Am J Cardiol.* 1991; 68(11):1188-1193.
- 16 Viitasalo M, Karjalainen J. QT intervals at heart rates from 50 to 120 beats per minute during 24- hour electrocardiographic recordings in 100 healthy men. Effects of atenolol. *Circulation.* 1992; 86(5):1439-1442.
- 17 Bexton RS, Vallin HO, Camm AJ. Diurnal variation of the QT interval--influence of the autonomic nervous system. *Br Heart J.* 1986; 55(3):253-258.
- 18 Browne KF, Prystowsky E, Heger JJ, et al. Prolongation of the Q-T interval in man during sleep. *Am J Cardiol.* 1983; 52(1):55-59.
- 19 Fritsch JM, Charles JB, Eckberg DL, et al. Effects of short-duration space flight on human carotid baroreceptor cardiac reflexes. *FASEB J.* 1990; 4(3):A429.
- 20 Whitson PA, Charles JB, Williams WJ, et al. Changes in sympathoadrenal response to standing in humans after spaceflight. *J Appl Physiol.* 1995; 79(2):428-433.
- 21 Fritsch-Yelle JM, Whitson PA, Bondar RL, et al. Subnormal norepinephrine release relates to presyncope in astronauts after spaceflight. *J Appl Physiol.* 1996; 81(5):2134-2141.
- 22 Levine BD, Pawelczyk JA, Ertl AC, et al. Human muscle sympathetic neural and haemodynamic responses to tilt following spaceflight. *J Physiol.* 2002; 538(Pt 1):331-340.
- 23 Hoffler GW, Johnson RL, Nicogossian AE, et al. Vectorcardiographic Results From Skylab Medical Experiment M092: Lower Body Negative Pressure. In: Johnston RS, Dietlein LF, editors. *Biomedical Results of Skylab.* Washington, DC: Scientific and Technical Information Office National Aeronautics and Space Administration, 1977: 313-323.
- 24 Schouten EG, Dekker JM, Meppelink P, et al. QT interval prolongation predicts cardiovascular mortality in an apparently healthy population. *Circulation.* 1991; 84(4):1516-1523.
- 25 Lerman BB, Engelstein ED, Burkhoff D. Mechanoelectrical feedback: role of beta-adrenergic receptor activation in mediating load-dependent shortening of ventricular action potential and refractoriness. *Circulation.* 2001; 104(4):486-490.
- 26 Bergman SA, Jr., Johnson RL, Hoffler G.W. Evaluation of the Electromechanical Properties of the Cardiovascular System After Prolonged Weightlessness. In: Johnston RS, Dietlein LF, editors. *Biomedical Results of Skylab.* Washington DC: Scientific and Technical Information Office National Aeronautics and Space Administration, 1977: 351-365.

- 27 Priori SG, Barhanin J, Hauer RN, et al. Genetic and molecular basis of cardiac arrhythmias: impact on clinical management parts I and II. *Circulation*. 1999; 99(4):518-528.

## Figure Legends

Table 1. Data are expressed as the mean  $\pm$  SEM. Serum concentrations of potassium ( $K^+$ ), magnesium ( $Mg^{++}$ ), and total calcium ( $Ca^{++}$ ) were obtained before flight, on landing day and 3 days after landing for short- and long-duration space flight.  $\dagger P < 0.01$

Figure 1. Individual corrected Q-T intervals (Q-Tc), measured during 60 seconds of supine rest, from a single astronaut before flight (left), on landing day after short-duration flight (middle), and after long-duration flight (right). Normal Q-Tc is 0.44 seconds or less.

Figure 2. Data are expressed as the mean  $\pm$  SEM. P-R and corrected Q-T intervals preflight, on landing day, and 3 days after landing for short (left)- and long (right)-duration space flight.  $*P < 0.05$ ,  $\dagger P < 0.01$ ,  $\ddagger P < 0.001$  NS = not significant.

Figure 3. The percent change in R-R interval length from preflight to landing day for short-duration (left) and long-duration (right) space flight.  $*P < 0.05$ .

Figure 4. P-R intervals for 3 crewmembers before flight, during a 4-month space mission, after transfer to the Space Shuttle, on landing day, and 11 or 39 days after landing. Note the increase in P-R interval and the sharp, transient decrease after transfer to the Shuttle.

Figure 5. Corrected Q-T intervals for 3 crewmembers before flight, during a 4-month space mission, after transfer to the Space Shuttle, on landing day, and 11 or 39 days after

landing. Note the increase in the Q-Tc interval and the sharp, transient decrease after transfer to the Shuttle.

Figure 6. R-R intervals for 3 crewmembers before flight, during a 4-month space mission, after transfer to the Space Shuttle, on landing day, and 11 or 39 days after landing. Note the increase in R-R interval and lack of change after transfer to the Shuttle.

**Table 1. Serum Electrolytes in Astronauts**

	Short-Duration (n = 5)			Long-Duration (n = 7)		
	Preflight	Landing	Postflight	Preflight	Landing	Postflight
K <sup>+</sup> (mmole/l)	4.2±0.10	4.2±0.15	4.2±0.09	4.2±0.09	3.8±0.09 <sup>†</sup>	4.1±0.11
Mg <sup>++</sup> mmole/l)	0.95±0.05	0.95±0.02	0.99±0.03	1.1±0.04	1.0±0.03	1.0±0.04
Ca <sup>++</sup> (mmole/l)	2.3±0.05	2.4±0.05	2.3±0.06	2.4±0.03	2.4±0.04	2.4±0.04











